United States Coast Guard
Shipboard Technology Evaluation Program (STEP)
For Experimental Ballast Water Treatment Systems
2004

BACKGROUND INFORMATION FOR THE APPLICANT

INTRODUCTION

The United States Coast Guard (Coast Guard) Shipboard Technology Evaluation Program (STEP) is designed to provide incentive to ship owners and operators to install experimental or prototype treatment systems with demonstrated potential for effective removal or destruction of aquatic nuisance species in ballast water. The Coast Guard and the applicant enter into an agreement whereby valuable experimental data accrues to the Government and the public at large and the applicant's vessel is accepted into the STEP for a specific period of time, during which operation of the experimental system is considered equivalent to meeting applicable regulatory requirements for ballast water management. This process involves the submission of large amounts of information to the Coast Guard, described separately in a detailed set of specifications, "Application Requirements", which enable a thorough evaluation by a Review Panel during evaluation of applications for acceptance into the program. Prospective applicants are strongly urged to review the Requirements document before reading this one, to get a broader perspective on the program's features in general and the technical organization of the review process in particular.

This document provides a more detailed level of guidance, so that the Government's expectations for well conceived experimental designs and proper testing protocols will be understood by applicants. It includes overviews of technical issues related to the main points of a program designed to evaluate the performance of a treatment system, including:

- Comparison of treatment system performance with that of ballast water exchange (BWE) on the vessel(s) for which an application is submitted.
- Biological experiments addressing the mortality and/or viability of all the organisms being tested, and reporting the results of the experiments.
- A clear and thorough presentation of the physical design and engineering of the system, and plans to maintain its reliable operation and monitor system performance.
- Submission of annual and quarterly reports on the system's operations and performance.

This guide follows the organization and numbering of the Application Requirements document.

1.0 Letter of Commitment

No guidance included here.

2.0 Environmental Compliance

2.1 Conditioning of Treated Water Prior to Discharge, and Assessment of Discharge Water

The Applicant must describe the effect of the treatment process on ship's ballast water, in particular the nature of any treatment residuals and byproducts and the water's suitability for discharge into coastal waters. Describe any actions necessary to "condition" treated water in order that it meet applicable clean water regulations prior to discharge.

If the treatment involves the use of oxidizers or other chemicals, describe the methods to be used to reduce any residuals before the ballast is discharged from the ship. If no methods are planned, provide backup data and calculations demonstrating that the chemical will naturally degrade in the tanks and not pose an environmental threat on release.

2.2 *Management of Treatment Waste Streams*

The Applicant must identify and characterize any treatment system side streams, for example filtered material, centrifugal concentrate, and waste or residual chemicals, and describe actions planned to properly manage and dispose of such waste.

2.3 Literature Search

The Applicant must provide the results of a literature search of published, peer-reviewed or 'gray literature' articles that address the potential environmental impacts of the proposed technologies. The literature search should address, but not be limited to impacts to threatened or endangered species and critical habitat. The literature search should reflect uses of the technologies beyond shipboard applications, to include industrial and water treatment applications.

2.4 Documentation

The Applicant must supply environmental compliance documentation stating that the storage, handling, and discharge of residual concentrations of any primary treatment chemicals or chemicals that occur as disinfection by-products meet all applicable local, state, federal, and tribal requirements, including those for environmental protection and human health and safety.

It should be understood that possession or review of these documents by the Coast Guard or its agents cannot be interpreted as approval, and that compliance with all applicable local, state, federal, and tribal requirements remains the sole responsibility of the Applicant. The application should include discussions of specific environmental, health, and safety matters arising from the installation and use of the treatment system.

3.0 Documentation of Prior Experiments Demonstrating Efficacy of the Applicant's Treatment System

In this section, the Applicant supplies the quantitative data and interpretations from previous experiments and trials that are directly applicable to the proposed shipboard tests. Ideally, shipboard testing is reserved for confirmation of performance and proper operations at full scale, under at-sea operating conditions. Issues such as required doses, system controls, etc. should be addressed before proceeding to full-scale final design and installation.

Prior experimentation would typically include laboratory-scale work on the core treatment technologies, resulting in, e.g., optimized dose/response curves, and minimum required treatment times. The appropriateness of the selected assays and other metrics is frequently confirmed during the laboratory-scale work. Ideally, preliminary work would also include pilot scale tests conducted dockside, on a barge, or in a large tank, and designed to address physical scale-up questions. These scale-up issues include the ability to achieve sufficient mixing in a larger tank, assessment of settling issues, operations and maintenance needs, as well as analytical procedures and sampling at a larger scale.

A criterion of 98% removal or destruction of zooplankton larger than 50 microns in preliminary experiments has been set for partial qualification for the STEP. The results from these tests should at least theoretically apply to the system installed on the vessel. If issues of scale are identified by the review panel, it may be necessary to complete additional preliminary experiments before reapplying to the STEP.

These steps typically precede a full-scale installation, which would have detailed engineering drawings and schedule, and equipment fully tested from engineering point-of-view. If either step has not been executed prior to full scale testing, the Applicant should offer a reasoned, scientific rationale for proceeding to full scale.

If system components have changed between the prior work and the system to be examined in the proposed shipboard trials, the Applicant is expected to explain fully the nature of the changes, and the reason the earlier data are still applicable to an evaluation of the current system. If system components have not changed mechanically, but have been renamed, please provide a concise explanation. Also, explain the similarities and differences of environmental conditions in prior experiments and those anticipated onboard during the proposed tests.

3.1 Laboratory Experiments (Bench Scale)

These experiments are meant to establish the abilities of individual treatment components' core technologies to accomplish the desired operations (proof of concept experiments), and to determine the key operational variables (design experiments). The analytical methods, assays, and other metrics employed to measure performance of the core technologies should also be worked out at this stage.

The equipment is, in usual practice, small in scale, and the experiments are often batch in nature. Full-size equipment should be avoided.

For example, bench scale tests should determine if centrifugal force will sufficiently remove microscopic organisms, the UV dose/inactivation curve for target species, or the chlorine demand and required residual for source waters.

An Applicant may have chosen to skip small or intermediate scale testing, but having done so must provide a clear rationale that offers the assurance that the treatment system has a reasonable chance of performing effectively, and that the larger scale experiment(s) will provide meaningful data. Well proven treatment technology and/or standard experimental procedures are clearly desirable aspects in such cases, as would be relevant laboratory results from elsewhere, if they exist.

3.2 Shore Side Experiments (Intermediate/Pilot Scale)

These experiments are intended to resolve the unforeseen issues encountered in the scale-up of processes, and the conversion of the technology from batch to semi-batch and continuous operations. System controls and materials of construction should be worked out at this stage. Equipment remains small in scale, but should be large enough to simulate the performance of full-size unit operations, for example, dockside or large tank size.

While analytical methods should remain unchanged (assuming they were properly investigated and adapted during bench-scale testing), field sampling techniques (collection, compositing, storage and shipping) should be worked out at this stage.

3.3 Onboard Experiments (Intermediate or Full Scale)

In some cases, applicants or vendors may have previously conducted experiments onboard the proposed ship or on other ships. If they choose to report those results, they should indicate all similarities and differences between the installations, addressing both the ship and the treatment system. In the former case, all systems affecting the treatment system should be compared, such as capacities, flows, valving, injection methods, risk of cross contamination. Further, the ship's operations and routes, and environment, health, and safety matters should be compared.

The Applicant should note all changes in the treatment componentry, made either as a result of lessons learned or in order to deal with a different ship. There should also be a comparison of experimental designs and protocols, noting similarities and differences, lessons learned, and adjustments to address the new experimental test bed (ship).

3.4 Data Submission Requirements

At a minimum, the Applicant should supply:

- For bench scale, detailed descriptions of experiments and equipment;
- For pilot and full scales, detailed descriptions of experiments, equipment, and system configurations; and
- Results and interpretation establishing the efficacy of the treatment approach (in terms of actual concentrations achieved and the percent difference between controls and treatments), the accuracy of the analytical techniques, appropriateness of the measured variables in predicting the system performance, and the efficacy of achieving similar results with a full-scale shipboard system.

4.0 Study Plan

4.1 Format Requirements

The application must first and foremost address all the points in the Applicant Requirements, and do so according to the logic and numbering common to all the STEP guidance documents. Any reference to other technical documents must be clearly explained and fully cited (e.g., page and figure numbers) in the application, and the reference materials must be included (e.g., drawings, vendor information, copies of relevant sections of scientific books or papers). References and appendices may not substitute for clear explanation in the body of the application.

4.2 Test Organization and Staff

Provide an overview of team structure and management, including lines of authority (e.g., owner representative, test director, supporting groups). An organizational chart is required, including all key test team personnel and their organizations (e.g., test director and other managers, technical staff, and support staff). The role of each in the development and execution of the test must be clear.

4.2.1 Ship Owner and Operator

Provide the name of the line and ship, owner identity and address, charter type and duration, and key shipboard personnel, particularly engineering staff to the degree practical. A point of contact in the company's shoreside staff is strongly recommended.

4.2.2 System Vendor(s)

For each company, provide: name, location, relevant component(s), and name and contact data for the field service representative(s) involved with test.

4.2.3 Test Team and Affiliations

Identify all members of the test team and their affiliations. Be sure to include the following staff i.e., the key management and technical leads:

4.2.3.1 Management

Include personnel responsible for schedules, funding, and logistics, particularly with regard to coordination of activities among the organizations involved.

4.2.3.2 Technical staff

Include the Principal Investigator for the onboard experiments, the top scientific personnel for each sub-discipline (e.g., plankton), and brief description of their qualifications.

4.2.3.3 Laboratories

Provide name, location, principal(s), affiliations with industry, academia, and government, capabilities and certifications.

4.2.4 Testing Flow Chart

A testing flow chart indicates who is responsible for all stages of sample collection, assay, transport, preservation, and data synthesis. The point is also to show basic assay specifications and rough time lines so that the samples' "life cycle management" can be seen at a glance. This includes sampling sites, number of repetitions, sample splits, and other features. For example, "bacteria samples will be processed within 24 hours", or "zooplankton samples (X Liters) will be collected from Y tanks using Z technique with XX repetitions, will be held at YY temperature in the dark, and will be transported to the laboratory onboard the ship in less than ZZ hours for processing".

4.2.5 Public Funding Sources

Identify all public funding sources, periods of performance, and amounts provided by each.

4.3 Description of Vessel and Ballast Water Treatment System

4.3.1 Test Ship, Location, and Conditions

Describe the following:

- Test ship name and IMO identification number and, if applicable, Coast Guard vessel identification number (VIN).
- Ship type/size/build year/general arrangements, route(s), home port, flag state, classification society, nationalities of officers and crew (particularly engineering staff), and characterization of local waters at both intake and discharge points to the extent possible, given advance knowledge of the ship's schedule, prior to site-specific tests.
- Description of existing ballasting/deballasting system and of any other systems with cross connections and the potential for cross-contamination between tanks and lines. The latter includes systems segregated by valves, for which description of the means of segregation should be included. The Applicant should also describe all compartments involved in any aspect of testing, including location of treatment system, ballast tank(s) and cargo hold(s) to be tested, and other compartments used for laboratory procedures, storage of equipment and materials, and administrative tasks.
- Description of arrangements for shipping of samples.

4.3.2 Treatment System Overview

Describe the following:

- Location and arrangement of treatment system in the vessel and its integration with existing equipment, all relevant piping modifications, system start-up and operating procedures;
- Materials of construction used, and confirmation that these materials are compatible with seawater.

4.3.3 Treatment Stages

This section of the Application Requirements includes subsections 4.3.3.1, .2, and .3: "Treatment stage #1/2/3". Most systems will consist of multiple treatment stages, which may or may not be described by the terminology "primary" and "secondary" treatment. Those terms apply to systems where physical removal or separation of organic and inorganic constituents is followed in sequence by a disinfection stage (e.g., filtration followed by UV radiation). Otherwise, applicants planning to use systems with multiple unit processes should simply refer to Stages 1, 2, etc. Discussion of individual treatment components follows, sorted as "primary" and "secondary" for convenience only. The Applicant must still complete sections 4.3.3.1, .2, etc.

Primary treatment

Primary treatment unit operations clean the incoming ballast water, removing particles, organisms, and/or chemicals before disinfection. The purpose of this removal action is to either protect downstream equipment from clogging or physical damage (due to the introduction of solid particles or oils), or to improve the efficiency of the disinfection stages (by reducing the total number of organisms, or removing solids/chemicals that interfere with the disinfection action).

The primary treatment technologies discussed herein are not comprehensive and include:

- Mechanical filters that physically block solid particles (basket, cartridge, pre-coat, and rapid filters);
- Accelerated settling devices that separate solids and fluids with densities greater than that of water (centrifugal and cyclonic separators); and
- Chemical filters that target soluble compounds (activated carbon).

These specific operations have been selected for discussion here because they are the processes most frequently encountered in drinking water treatment that may be applicable to ballast water treatment, or have been observed in existing ballast water treatment systems. Inclusion of these operations in this document does not mean the Coast Guard believes the processes are necessary or recommended. This questionnaire omits common operations that are probably not suitable to installation onboard a ship, such as gravity clarifiers (which require a steady environment).

The Applicant should assess source water quality and identify the general classes of contaminants in the incoming ballast water that could affect treatment processes. Such contaminants should be addressed in the contexts both of the physical vulnerability of downstream equipment, and the effectiveness of the treatment system. For example, if the source waters going into a UV treatment system contain substantial amounts of organic compounds known to absorb UV radiation, then the application should address the issue by reducing the concentration of organic compounds, adjusting the UV dose, or some other appropriate measure.

Below are listed the general classes of contaminants that may be encountered in source waters, along with some of the major benefits obtained by the design choice of removal.

- Dirt, grit, silt, and other generic solid particles – Removal protects downstream equipment, and maintains “cleaner” ballast tanks.
- Viable Organisms – Removal reduces the number of organisms to be killed and lessens the scavenging of oxidizers and free radicals intended to attack organisms, and provide fewer food sources for organisms in ballast tanks.
- Immiscible Organics – Removal reduces the potential for fouling downstream equipment, decreases absorbance of UV, lessens the scavenging of oxidizers and free radicals intended to attack organisms, and provides fewer food sources for organisms in ballast tanks.
- Dissolved Organics – Removal decreases absorbance of UV, lessens the scavenging of oxidizers and free radicals intended to attack organisms, and provides fewer food sources for organisms in ballast tanks.

The following bullets identify some suggested treatment options for source water contaminants, should the removal option be chosen. The listing is not comprehensive and applicants may propose other means of achieving the desired results.

- To remove suspended solids (dirt, grit, silt, organisms, etc.), use:
    - Mechanical filtration (down to a given particle size);
    - Accelerated settling (heavy particles only); and/or
    - Chemical flocculants (e.g. alum, polymers, ferrous chloride) to aid removal by mechanical filtration or accelerated settling.

- To remove immiscible organics (oil, dense non-aqueous phase liquid [DNAPL], etc.), use:
    - Accelerated settling (DNAPL only); and/or
    - Activated carbon.
- To remove dissolved organics (pesticides, volatile organic compounds (VOC), etc.), use:
    - Activated Carbon.

The Applicant should provide the following information:

- Any target contaminant classes that need to be removed as part of the treatment process: generic solid particles; viable organisms (identify in general terms, e.g., viruses, photosynthetic bacteria, etc. {see guidance provided in 4.3.2.1}), immiscible organics, and/or dissolved organics;
- The desired effect of the removal (i.e., why is this removal important for the operation of the system?);
- The technology that will accomplish this removal; and
- How/why this technology is expected to accomplish this removal.

The Applicant should also provide material safety data sheets (MSDS) for any chemicals used during primary treatment.

The following section discusses in more detail some of the important issues related to specific kinds of primary treatment processes.

Primary Treatment – Mechanical Filtration Module

General Description

Mechanical filters work by physically preventing the passage of suspended solids, while allowing the passage of liquids. Mechanical filtration will not separate different liquids, and will not separate dissolved solids (except reverse osmosis [RO] membranes). The pressure drop across the unit will increase with solids loading, requiring routine solids removal. Most units require batch-wise cleaning: the pressure drop increases until a predetermined value is achieved, at which point the unit is brought offline for cleaning. Some basket filters incorporate an automatic vacuum mechanism ("self-cleaning" models), allowing for continuous, stable operations.

A. Basket Separation

Discussion

Basket filters are designed to remove large particles (pebbles, leaves, sticks, fish, etc.). These units operate by passing the fluid through a perforated bucket (the basket), and typically have a low initial pressure drop. Cleaning consists of bringing the unit offline, and removing and emptying the basket. Duplex models are available that allow for the switching of flow from one unit to another through the use of a single handle.

Key technical points

In addition to providing shop drawings showing the external and internal construction of the unit, the Applicant should identify the following specifications:

- Design flowrate;
- Simplex or duplex design;

- Materials of construction;
- Basket perforation size;
- Physical dimensions;
- Pressure drop equation; and
- Maximum pressure rating (temperature dependent).

B. Media and Cartridge Separation

Discussion

Media filters are frequently used to remove smaller particles (sand, silt, floc, some microbes, etc.) than are removed by basket filters. Removal of these smaller particles is aided by the addition of flocculants (inorganic salts that cause particles to clump together due to electrostatic charges) and certain polymers (long, water soluble molecules that attract and "entangle" particles). Media filters typically require protection from large particles, and it is not uncommon to see them coupled with clarifiers (large, static systems) or basket filters. Large, pressurized housings should be equipped with a burst disk in the event the media becomes clogged. Common media filters include cartridge, pre-coat, and granular filters.

i. Cartridge Filters

Discussion

Cartridge filters house a media composed of membranes, fabric, or string. Cleaning is through cartridge replacement. Cartridges are easy to exchange, but typically must be disposed of after a single use. Duplex models are available that allow for the switching of flow from one unit to another through the use of a single handle.

Key technical points

In addition to providing shop drawings showing the external and internal construction of the unit, the Applicant should identify the following specifications:

- Design flowrate;
- Simplex or duplex design;
- Materials of construction;
- Cartridge type/construction/rating;
- Physical dimensions; and
- Pressure drop at which a cartridge will be replaced.

ii. Pre-coat Filters

Discussion

Pre-coat filters house a thin layer of fine media (diatomaceous earth) supported by permeable septum. Solid loading occurs on the surface of the media. A "body feed" may be introduced into the influent to control the density of buildup on the septum. Cleaning is through backwashing of the filter, resulting in the removal filtered solids and pre-coat layer. A new pre-coat layer is introduced by sending a fluidized stream of the fine media to the filter. Large particles may damage the septum.

Key technical points

In addition to providing shop drawings showing the external and internal construction of the unit, the Applicant should identify the following specifications:

- Design flowrate;
- Unit construction;
- Septum surface area;
- Pre-coat media type;
- Body feed type and design feed rate;
- Materials of construction;
- Pressure drop at which filter will be backwashed;
- Storage and/or disposal of backwash effluent; and
- Burst disk rating.

iii. Pressurized Granular Media Filters (Rapid Filters)

Discussion

Rapid filters house thick layer(s) of course media (sand, anthracite coal, and/or other particulate material). Loading occurs throughout the depth of the media. Backwashing removes filtered solids, but not media. Large particles may become imbedded in media, assisting the formation of bypass channels in the media ("rat holes"). Also, the fouled media may clump together, resulting in the same effect as the introduction of large solids. As such, the media may need to be changed from time to time. Care should be taken to avoid the entrainment of large masses of biological material (dead fish, etc.), as these will serve as a breeding ground for bacteria, and possibly result in localized anaerobic conditions.

The media characteristics (type, size, depth, etc.) will determine the nature of the solids removal. The underdrain supports the media, and its construction influences the effectiveness of the backwashing.

Frequently, these units are installed in a duplex fashion (although not marketed as such). Switching from one unit to the other, and the control of the backwash sequence are typically automated, with the appropriate valves being operated by a programmable logic controller (PLC). The pressure drop across the active unit, total flow, or total elapsed time may be used to determine the frequency of the backwashing.

Key technical points

In addition to providing shop drawings showing the external and internal construction of the unit, the Applicant should identify the following specifications:

- Design flowrate;
- Design surface loading (empty bed velocity per unit cross-sectional area);
- Unit construction;
- Materials of Construction;
- Underdrain design;
- Media type(s) and depth(s);
- Media grain density(ies), loose-bed porosity(ies), sphericity(ies);
- Media grain size distribution(s);
- Design clean pressure drop;
- Pressure drop / volumetric flow / time at which filter will be backwashed;
- Storage and/or disposal of backwash effluent; and
- Burst disk rating.

Primary Treatment – Accelerated Settling Module

General Description

Accelerated settling unit operations expose the fluid to high g-forces through circular motion. Different or immiscible phases segregate based on densities (typically expressed as specific gravity). While the required settling time is significantly less, accelerated settling unit operations will not segregate species unaffected by gravity clarifiers (solids and liquids with similar densities will not be separated). Common types include centrifugal and cyclonic separators.

A. Centrifugal Separation

Discussion

Centrifugal separators are typically used for liquid/liquid or liquid/solid applications. The energy needed to spin the fluid is supplied by an external motor. As such, these devices are effective over a wide range of flowrates.

Key technical points

In addition to providing shop drawings showing the external and internal construction of the unit, the Applicant should identify the following specifications:

- Design (maximum and minimum effective) flowrates;
- Physical dimensions;
- Materials of construction;
- Motor horsepower (HP) rating;
- Target g-force; and
- Particle size removal efficiency (a function of density and range of flowrates – this information is frequently supplied as a series of graphs).

B. Cyclonic Separation

Discussion

Cyclonic separators are typically used for gas/solid applications, but commercial models for liquid/solid applications are on the market. The energy required to spin the fluid is supplied by the stream. While this design avoids an external motor and moving parts, the units are restricted to operating over a small range of flowrates. Further, they may not generate g-forces as great as a centrifuge, thereby limiting their ability to remove particles that are small, or have densities close to that of water.

Key technical points

In addition to providing shop drawings showing the external and internal construction of the unit, the Applicant should identify the following specifications:

- Design (minimum and maximum) flowrates;
- Physical dimensions;
- Materials of construction;
- Pressure drop at the design flowrate;
- Target g-force; and

- Particle size removal efficiency (a function of density and the range of flowrates – this information is frequently supplied as a series of graphs).

Primary Treatment – Chemical Filtration (Carbon Adsorption) Module

Discussion

Dissolved organics will adsorb onto the surface of carbon. A process known as "activation" significantly increases the available surface area by unblocking and enlarging pores in the carbon. Carbon is activated by exposure to low pressure (atmospheric), high temperature (1,000°C) steam. The byproducts are carbon monoxide and hydrogen gas. Carbon made from coconut husks is preferred due to its superior mechanical strength and large distribution of pore sizes.

Carbon vessels resemble granular filters in construction. Although less dense than anthracite, the carbon grains are of similar size and shape. Carbon vessels are typically preceded by mechanical filtration to prevent fouling. Backwashing of the carbon vessels will reduce the effects of fouling, but will not completely recover the lost capacity, and will reduce the grain size distribution due to collisions between the carbon particles.

Carbon adsorption vessels are frequently installed as two in series. After the lead carbon vessel reaches saturation (achieves breakthrough), it is taken offline. The lag vessel then becomes the sole operational vessel until the lead vessel's carbon is regenerated or exchanged. For liquid phase carbon, regeneration is accomplished by repeating the activation process. (Given the high temperature requirements, it is unlikely that the carbon will be regenerated onboard the ship.) After carbon replacement, the operating vessel becomes the lead, and the newly filled vessel becomes the lag. System valves and piping will need to be suitable arranged to allow for this change in order.

Reactivation will remove most of the absorbed organics, but it will also weaken the mechanical strength of the carbon and decrease the particle size distribution (increasing the associated pressure drop). 100% recovery of the surface area in the pores should not be expected. As a result of the above, reactivated carbon is inferior to (and less expensive than) virgin carbon. A measure of a carbon's quality is its Iodine Adsorption Number, as measured by ASTM D4607.

Virgin or reactivated carbon will release significant amounts of heat when first wetted, and will initially remove oxygen from the water. These facts should be considered if the carbon is shipped dry. (This occurrence will be rare, however, as carbon intended for liquid-phase use is typically shipped as a water-suspended slurry.)

Key technical points

In addition to providing shop drawings showing the external and internal construction of the unit, the Applicant should identify the following specifications:

- Design flowrate;
- Design surface loading (empty bed velocity per unit cross-sectional area);
- Physical dimensions;
- Materials of construction;
- Carbon supplier;
- Virgin or regenerated carbon;
- Iodine Adsorption Number (ASTM D4607);
- Carbon grain density(ies), loose-bed porosity(ies), sphericity(ies);

- Carbon grain size distribution(s);
- Design clean pressure drop;
- Method for determining breakthrough;
- Pressure drop at which filter will be backwashed or taken offline;
- Storage and/or disposal of backwash effluent; and
- Burst disk rating.

Secondary Treatment (Disinfection)

Secondary treatment unit operations disinfect the incoming ballast water, inactivating the viruses, bacteria, phytoplankton, zooplankton, and higher organisms, including cysts and other dormant stages. The goal is to prevent the release of viable organisms in the ballast water discharge. Treatment systems that require the action of a chemical residual (e.g. chlorine addition) typically treat only the influent ballast water, and rely on the residence time of the ballast tanks to ensure the appropriate level of disinfection is achieved. Treatment systems that lack residual disinfection may treat both the influent and effluent ballast water (e.g. ultraviolet radiation), or may be applied directly and continuously to the ballast tanks (e.g. ozone).

Secondary treatment technologies discussed herein include:

- Ultraviolet radiation (UV);
- Ozone;
- Chlorine;
- Other oxidizing chemicals;
- Non-oxidizing chemicals (biocides);
- Heat; and
- Other methods.

These specific operations have been selected because they are the processes most frequently encountered in drinking water and municipal wastewater treatments that are applicable to ballast water treatment, or have been observed in existing ballast water treatment systems.

Discussion

The mechanism of inactivation varies among the different disinfection approaches. Understanding a treatment system's mechanism of inactivation is important, and it will determine the organisms vulnerable to inactivation, and the conditions under which the approach will be successful.

UV inactivates organisms by disrupting the DNA. Ozone, chlorine, and other oxidizing chemicals work by oxidizing broad classes of chemicals within the cells of the organisms, whose target areas (outer membrane, internal cytoplasm, etc.) vary according to the oxidizer used. Non-oxidizing biocides sterilize by disrupting specific steps in the organisms' metabolism. These chemicals may have an oxidative potential, but are frequently used at concentrations too low for oxidation to be the inactivation mechanism (e.g. bromine-based biocides used for the control of aerobic bacteria in cooling towers). In addition to these methods, Applicants may propose other innovative approaches (deoxygenation, heating, etc.).

In addition to the above, some Applicants may also couple several systems together. For example, the simultaneous use of ozone, hydrogen peroxide, and UV.

Key technical points

At a minimum, the Applicant should identify:

- The inactivation approach (UV, chlorine, etc.);
- The target organisms, e.g., viruses, photosynthetic bacteria, etc. (see guidance provided in 4.3.2.1);
- The mechanism of inactivation (oxidation of sulfur bonds, disruption of DNA, etc.);
- Potential hazards, including residuals and byproducts; and
- The name and contact data of the equipment manufacturer and its field representative supporting the test program.

The Applicant should also provide material safety data sheets for any chemicals used during primary treatment.

Disinfection – UV Module

General Description

Ultraviolet radiation (UV) may be used to inactivate bacteria and viruses. UV disrupts the DNA, rendering the organisms sterile. The optimum wavelengths for inactivation are between 250 and 265 nanometers (nm).

UV may inactivate other organisms, but an industrial rule of thumb holds that UV will not inactivate those visible to the human eye. Further, organisms that have evolved to exist in the sun-bathed upper layers of the water column may be especially resistant to inactivation with UV. UV will not provide residual disinfection in the ballast system.

The level of inactivation for a given species is determined by the applied UV dose. The dose is a direct function of the UV intensity and exposure time, and is typically expressed in units of milliwatt-seconds per square centimeter (mW-sec/cm^2). For a given reactor, the manufacturer should calculate and provide the UV dose at the design flowrate.

The dose required for a given percent inactivation varies significantly among species. Species-specific UV dose tables (e.g., Tipton Environmental International – Wastewater Treatment Company website: http://www.wastewaterdepot.com/engineer/uvtechinfo.pdf) are available for 99.9% inactivation of selected freshwater species of concern in the treatment of drinking water and waste water (values range from 4 to 440 mW-sec/cm^2). Tables for saltwater species were not located in the literature, but it is reasonable to expect a similar range.

The UV absorbance and scattering characteristics of the water will affect the dose applied to the organisms. UV absorbance occurs due to the presence of dissolved molecules, such as tannic acid, dyes, and nitrogen-containing organic compounds (e.g. pesticides). UV scattering occurs due to the presence of suspended solids, such as clays, silts, and organic debris. As an industry rule of thumb, the transmittance at 253.7 nm (a measure of the UV absorbance) should be greater than 80% (greater than 90% preferred) of the transmittance of distilled water, and the total suspended solids present should be less than 20 milligrams per liter (mg/L) (less than 10 mg/L preferred). These water quality parameters should be measured in the source waters and supplied to the reactor manufacturer before the reactor UV dose is calculated, if the ship's operations and schedule are known. If not, then the Applicant should attempt to determine a rough range of these parameters for anticipated operating conditions.

UV reactors consist of a housing and a UV source. The geometry of the housing determines the exposure time at a given flowrate. The UV source determines the UV intensity for a given water quality.

The housing is typically constructed of stainless steel. Note that this material of construction may result in corrosion problems if exposed to saltwater. The UV source is typically a bank of mercury vapor lamps in quartz sleeves. The lamps need to warm up before water treatment begins. The quartz sleeves require routine cleaning. Some units incorporate internal wipers for this cleaning.

Low-pressure and medium-pressure mercury lamps are available. Low-pressure lamps are more efficient than medium-pressure lamps, and are more frequently encountered in industry. They have a sharp spectral peak at 253.7 nm. The anticipated lifespan for continuous operation is approximately 8000 hours. On/off cycling, as may be anticipated for onboard treatment, can significantly affect the lifespan, with reductions of up to 50 percent of hours of operation.

Medium-pressure lamps emit a broad spectrum, rather than a sharp peak. 25% of their energy is emitted in the germicidal spectrum. Although less efficient, the output of medium-pressure lamps are much greater than that of low-pressure lamps. The germicidal output of one medium-pressure lamp is equivalent to that of 6 to 16 low-pressure lamps. The continuous operations lifespan of a medium-pressure lamp is 2,000 to 5,000 hours.

Controls may be required to maintain a constant dose with changes in water quality, quartz sleeve fouling, and lamp age. The typical approach is to measure the UV intensity at a fixed point away from the bank of lamps, and adjust the flowrate (and thus the exposure time) accordingly. This approach may adversely impact the performance of other unit operations that rely on a constant flowrate (e.g. cyclonic separators). Additional instrumentation may include low output and lamp out/malfunction alarms.

Unprotected UV may result in blindness (symptoms often occur after exposure). The lamps should never be viewed directly when energized. The housing should provide adequate protection for the workers, and have appropriate and visible warning labels.

Key technical points

- Design flowrate;
- Calculated UV dose at design flowrate (include data/assumptions – water quality, lamp age, etc.);
- Type and number of UV lamps;
- Unit construction;
- Materials of construction;
- Control approach and alarms (sensors, controllers, and other instrumentation);
- Design pressure drop; and
- Maximum operating pressure.

Disinfection – Ozone Disinfection Module

General Description

Exposing gas-phase oxygen (in air or as a pure gas) to ultraviolet radiation or a high voltage silent plasma (corona) discharge will generate ozone. Humidity and organic compounds will reduce the efficiency of corona discharge generators.

When exposed to liquid water, ozone generates free radicals (HO_2 and HO). Bacteria are inactivated by cell wall disintegration. Ozone is also considered effective against viruses, but literature does not provide the mechanism. Ozone does not provide residual disinfection in fresh water. The bromide ion (Br^-) in seawater reacts with ozone, and an equivalent amount of HOBr is formed. HOBr is a strong disinfectant; therefore there is little loss of disinfection potential with the reaction.

Ozone attacks the double bonds of unsaturated hydrocarbons. As such, it destroys phenolic compounds, bleaches organic color (including humic acid), and degrades some pesticides.

Direct contact of the organisms or chemicals with the ozone-rich bubble surface is more important than the reaction with dissolved ozone. Injection systems are designed to maximize the ozone bubble surface area.

The effectiveness of a contact chamber is measured by the "transfer efficiency", that equals the percent of ozone in carrier gas reacted or transferred into the liquid phase. It is determined from the Applied Ozone Dose (dose in the carrier gas) and the Absorbed Ozone Dose (dose reacted or absorbed by the liquid). The dose control strategy is frequently based on effluent gas concentration or Oxidation-Reduction Potential (ORP). Measurement of the residual concentration is not practical for control purposes due to ozone's rapid degradation.

Key technical points

In addition to providing shop drawings showing the external and internal construction of the generator, contact chamber, and appurtenances, the Applicant should identify the following specifications:

- Design gas flowrate (scfm);
- Design ballast water flowrate (gpm);
- Materials of construction used for housing and piping;
- Physical dimensions;
- Use of air or oxygen;
- Method of drying (if applicable);
- Oxygen method of generation (if applicable);
- Safety of oxygen transportation and storage (if applicable);
- Design ozone production rate (mass per unit time);
- Method of Ozone generation (Corona discharge or UV);
- Voltage (4000 – 30,000 V) and frequency (50-60 Hz to Microwave) of electricity used to generate the corona discharge (if applicable);
- Dielectric material of construction (ceramic or glass) (if applicable);
- Number of UV bulbs, rated wattage of each, and projected bulb life (if applicable);
- Ozone transfer efficiency;
- Details of ventilation near ozone generator; and
- Details of ambient air ozone detectors.

Disinfection – Chlorine Disinfection Module

General Description

Chlorine is available as Cl_2 (chlorine gas), NaOCl (chlorine bleach), $Ca(OCl)_2$ (bleaching powder), and chloramines (chlorine plus ammonia). When exposed to water, chlorine generates the hypochlorite ion (OCl^-). Hypochlorite will diffuse through the cell walls of bacteria, and attack the enzymes. This action disrupts respiratory, transport, and nucleic acid activity. Hypochlorite degrades the nucleic acid or protein coat of viruses.

The Applicant should address the half-life of chlorine, or any other chemical proposed for use in the system. Half life will vary according to water conditions - pH, temperature, suspended solids content, etc. The working assumption should be that enough oxidizer is added to reduce any organics or other sources of chemical oxygen demand, with some residual left in the water to kill emergent organisms. For the more resilient oxidizers such as chlorine, reduction of the residual with something like bisulfite or carbon may be necessary.

Key technical points

In addition to providing shop drawings showing the external and internal construction of the equipment, the Applicant should identify the following specifications:

- Physical dimensions;
- Materials of construction;
- ORP, chlorine residual, or flowrate control;
- Associated control equipment;

If chlorine gas is to be used:

- The gas source - compressed gas or liquid cylinders (liquid cylinders require evaporator and gas filter);
- Dosage;
- Metering system;
- Injector system;
- Estimated leak rates, venting, and contingencies;
- Sensors/alarms; and
- Safety of transportation and storage

If liquid sodium hypochlorite is to be used:

- The hypochlorite source – liquid storage or electrolysis of salt water;
- Concentration of virgin hypochlorite;
- Dosage;
- Metering system; and
- Injector system;
- If solid calcium hypochlorite is to be used:
- Mixing system (will likely need to be injected as a concentrated solution);
- Dosage;
- Metering system; and
- Injector system.

Disinfection — Other Oxidizers Module

General Description

In addition to chlorine and ozone, numerous other oxidizers are available. As a rule, they generate free radicals that attack organic compounds. The specific molecules attacked are determined by the stability of the oxidizer, and its solubility in various components of an organism's cells. The oxidizers discussed herein include hydrogen peroxide, peracetic acid, and chlorine dioxide.

Hydrogen peroxide is a metabolic byproduct of some cells. These cells contain catalase and peroxidase enzymes to decompose peroxides. Sufficiently high concentrations of hydrogen peroxide will overwhelm this mechanism. Personnel should avoid direct contact with concentrated hydrogen peroxide and should be aware that the process may generate free oxygen gas.

Peracetic acid, formed by reacting hydrogen peroxide with acetic acid (vinegar), is not decomposed by catalase and peroxidase. It exhibits a greater solubility in lipids than hydrogen peroxide, and will readily penetrate the cell membrane's lipid bi-layer. Peracetic acid attacks the sulfur bonds of key proteins, changing the conformation of the proteins and thereby inactivating them. Peracetic acid is a weak carcinogen when concentrated. Personnel should avoid direct contact with it. The process may generate acetic acid fumes, and appropriate containment and venting are required.

Chlorine dioxide is a gas that is generated on site by either the acid-chlorite or chlorine-chlorite process, and is soluble in water. It will disrupt protein synthesis in bacteria, and inactivate capsid functions in viruses. Chlorine dioxide should be considered more toxic than chlorine gas, and appropriate containment and venting are required.

The Applicant should address the half-life of any chemical proposed for use in the system. Half life will vary according to water conditions - pH, temperature, suspended solids content, etc. The working assumption should be that enough chemical is added to reduce any organics or other sources of chemical oxygen demand, with some residual left in the water to kill emergent organisms. For the more resilient oxidizers, reduction of the residual with something like bisulfite or carbon may be necessary.

Key technical points

In addition to providing shop drawings showing the external and internal construction of the equipment, the Applicant should identify the following specifications:

- Physical dimensions;
- Materials of construction (that is, their integration with existing ship system materials, resistance to corrosion, and compatibility with treatment environment);
- ORP, residual, or flowrate control;
- Associated control equipment;
- Details for the storage (or generation), metering, and injections systems;
- Estimated leak rates;
- Venting/containment methods;
- Contingencies in the event of a catastrophic failure; and
- Sensors and Alarms.

Disinfection – Non-Oxidizing Biocides Module

General Description

Other biocides inactivate organisms through reactions other than oxidation. Some of these biocides may be oxidizers, but work at concentrations too low for oxidation to be the principle mechanism of inactivation. Frequently, these chemicals will disrupt key portions of an organism's metabolism. Means to accomplish this task may include non-destructively blocking or interfering with an important chemical reaction (binding to the active site of specific enzymes, perhaps), or by destroying the specific constituents needed for the reaction (for example, permanently changing the conformation of an enzyme).

It is important to understand the mechanism of attack, as this series of reactions will define what organisms are affected, and under what conditions the biocide will be effective. Commercially established biocides are typically well researched, and their specific reactions understood. The Applicant who proposes a biocide should be able to explain the mechanism on a biochemical level, in order to confirm on a theoretical basis that the target organisms will be inactivated, and to understand the human and environmental health effects in the event of an accidental release.

The Applicant should address the half-life of any chemical proposed for use in the system. Half-life will vary according to water conditions - pH, temperature, suspended solids content, etc. The working assumption should be that enough chemical is added to reduce any organics or other sources of chemical oxygen demand, with some residual left in the water to kill emergent organisms. For the more resilient oxidizers, reduction of the residual with something like bisulfite or carbon may be necessary.

Key technical points

Applicants proposing to use a non-oxidizing biocide should provide the following information:

- Physical properties (biocide freezing point, melting point, density, etc.);
- Chemical properties (molecular composition and structure, generic chemical behavior, etc.);
- Safety information (conditions required for safe transportation and stable storage, incompatibilities with other chemicals, potential for hazardous decomposition or polymerization, first aid procedures, etc.);
- Mechanism of attack (should address the specific biochemical reactions that accomplish the inactivation – e.g. "blocks enzyme A by binding to the active site, thereby disrupting this portion of the metabolism");
- Organisms attacked (should be consistent with above mechanism – e.g., the Applicant should not claim that a biocide targeting chlorophyll inactivates viruses or aerobic bacteria, unless a second mechanism is provided justifying this claim {see also 4.3.2.1});
- Metering/dosing equipment specifications (including the materials of construction);
- Controls of metering/dosing; and
- Health and safety engineering controls, e.g., double-walled pipe or placement of alarms.

Disinfection –Other Treatment Methods

General Description

Some Applicants may propose methods of inactivation that do not fall under the classifications discussed in the previous sections. Examples include heating the ballast water, or applying a vacuum or nitrogen gas to deoxygenate it. If the proposed method is an established inactivation technique, it is important to confirm that the proposed operating conditions are consistent with those currently used in practice by others.

Applicants proposing "novel" techniques may, in fact, be proposing methods that previous drinking water engineers and scientists have researched and rejected long ago (either because the method was ineffective, only inactivated a limited class of organisms, was impractical, or cost prohibitive when compared to other available methods). This is not to say that some researchers will not develop innovative methods that can be successfully applied to the treatment of ballast water. Rather, when an Applicant claims that a technique is a novel approach, it may be worthwhile to invest some time and effort researching water treatment literature for prior experience with the suggested approach.

If, after researching the available literature, a method or application appears to be a novel technique, it will not be unreasonable to hold the Applicant to a higher burden of proof than that applied to Applicants marketing systems based on established approaches. It may be argued that by opting to pursue a novel technique, these Applicants have chosen to discard the benefits of previous research by others.

Key technical points

Given the variety of treatment schemes and systems possible, it is not practical to provide detailed questions covering all possible combinations not addressed in the previous sections. However, below are general guidelines for the type of information to be provided by the Applicant that should (if supplied in sufficient detail) provide a clear understanding of the treatment approach and its feasibility:

- Mechanisms or means of inactivation (should be specific – "denatures the proteins in the membrane, lysing the cells", etc.);
- Implementations and equipment (customize according to the equipment proposed, previous sections will provide a good starting point);
- Controls (customize according to the equipment proposed, previous sections will provide a good starting point);
- Health and safety considerations (customize according to the equipment proposed, previous sections will provide a good starting point);
- Applicable experience of Applicant; and
- Prior implementations of the system or approach, either by the Applicant or others.

4.3.4 Powering and Other Engineering Matters

The Applicant must provide essential engineering data on the treatment components' requirements for ship's power, connections to piping systems, interface with ship's monitoring and control, foundation design criteria, arrangement considerations (area and volume requirements, placement in particular compartments or proximity to particular systems), and waste management issues. These matters may be also be addressed in Section 4.4.

4.3.5 Controls and Monitoring

The control and monitoring of a ballast water treatment system will typically occur on three levels: within a unit operation (a UV reactor's control panel monitoring that the lamps turn on), between unit operations (a flowrate control valve throttling due to a low intensity reading in a UV reactor), and between the treatment system and the ship (the ship's control room instructing the UV reactor to warm up prior to ballasting).

Unit operation control and monitoring devices are typically restricted to sensors and alarms that ensure the unit operation is functioning properly. These sensors and alarms are intended to indicate when equipment repair or maintenance is necessary. Examples include temperature and intensity sensors in a UV reactor, ozone gas alarms in the ambient air around an ozone generator, and pressure gauges on filters. As with the pressure gauges, the sensors and alarms may be mechanical in nature, and do not necessarily generate an electronic signal that may be tied to a control panel or remote alarm.

Interlocks between the control and monitoring devices of different unit operations are intended to coordinate the different activities of the operations to ensure that the treatment system as a whole functions properly. Note that the focus tends to be on coordination, not detecting malfunctions.

Interlocks between the treatment system and the ship serve three purposes: to coordinate the system operation with ballasting/deballasting activities, to allow for the remote control of the system, and to allow the remote display of significant alarms.

Key technical points

The unit operation sensors/alarms and control logic should have been described when responding to the unit operation design questions above. Also, all controls, monitoring devices/sensors, and interlocks should be labeled on the Piping and Instrumentation Diagrams (P&IDs) to be provided under Section 3.4.1.4 of this Questionnaire. Under this section, the Applicant should provide:

- Detailed descriptions (including model numbers and catalog cut sheets) of any sensors, alarms, controllers, or other instrumentation not previously addressed in the responses to this Questionnaire.
- A prose summary of the controls and interlocks used to coordinate the operations of the treatment system as a whole.
- A prose summary of the controls and interlocks used to coordinate the treatment system with the ship's operations.

4.4 Experimental Design and Protocols

4.4.1 General Description

This section addresses the "primary experiments" referred to in NVIC 01-04. "Performance monitoring" is addressed mainly in section 4.7, with limited reference in section 4.4 to the correlation between primary experiments and performance monitoring. The Applicant is expected to provide an overview outlining the experimental program to be implemented in the treatment study, addressing the following major points.

A critical element in the experimental design is the ability to provide proper controls with which to specifically compare the effectiveness of treatment. Ideally, control samples would be subjected to identical manipulations during the study, except for the specific treatment to be measured. Additionally, non-manipulated controls may be included to gauge "bottle or storage effect" alone, but not to the exclusion of the directly comparable controls.

Sample collection and manipulation should minimally affect the viability of the test organisms under study. Sampling points subjecting organisms to damaging shear forces should be avoided (e.g., forcing sample through sharp bends at high velocity; passage of sample through gear pumps for the purpose of sampling). If physical sheer is unavoidable, such as passage through a ballast pump, the treatment and control water streams should be identically subjected to the potentially damaging manipulation. Subjecting treatment and control streams to differing sources of sheer or damage (e.g., passage of one stream through a single pump and the other stream through two pumps) will confound proper interpretation of the data.

If differential manipulation is unavoidable because of the physical design of an installed treatment system, for example, then a second set of controlled experiments should be conducted to specifically address the effect of the additional source of damage. An experimental program in which control samples are killed nearly as completely as samples subjected to the treatment does not constitute a well-designed experimental program.

Some mortality may be found in controls, as organisms retained in experimental test apparatus will likely be subjected to conditions significantly different from the natural environment. A well-designed test program will possess sufficient statistical robustness to readily distinguish with confidence the effects of treatment relative to controls that possess modest mortality.

4.4.2 Goals for Treatment Effectiveness by Target Taxa

4.4.2.1 and .2 Treatment Effectiveness on Target Taxa and Comparison to Ballast Water Exchange Effectiveness

Discussion

The applicant should collect sufficient data to establish the treatment system's effectiveness, and the effectiveness of ballast water exchange, through the quantitative assessment of numbers of potential colonizing entities. The predominant focus of the organism testing should be on using assays that directly and quantitatively assess, or provide a calibrated proxy assessment of, organism mortality, viability, or potential to propagate. The study plan should include experiments, assays, and data collection for the target organisms shown in the table below. The table also indicates example experiments and assays and includes comments explaining the validity of those choices or the problems with other approaches.

Target Organisms	Example Experiments and Assays	Comments
Viruses	Viable Plate Counts Phage Methods	Dilution series and growth into plaques
Bacteria	Viable Plate Counts	Dilution series and growth into colonies
Phytoplankton	Species-Specific Enumeration Immediately After Treatment	The standard cell count approach does not indicate viability
	Species-Specific Enumeration During "Grow Out" Experiments	Change in numbers over time indicate viability of cells following treatment
Cysts and Dormant Stages	Quantitative Microscopic Assessment of Germination	Determination of fraction of dormant stages that are able to germinate, relative to controls
Zooplankton and Higher Organisms	Species-Specific Enumeration with Viability Scoring	Viability observed through organism movement, response to stimulation activity of "organs" (heart, cilia, flagella, etc)

Key technical points

The study plan should provide information on the testing or justification for the omission from the test program of the following taxa and address the questions below:

Viruses _____

Bacteria, vegetative cells _____

Bacterial spores _____

Phytoplankton vegetative cells, species studied _____

Phytoplankton spores, cysts and resting stages _____

Heterotrophic and autotrophic protists _____

Zooplankton species studied _____

Zooplankton developmental stages studied _____

Larval forms of taxonomically higher groups (e.g., fish larvae) _____

- What is the rationale for choosing the indicated taxa?
- What is the rationale for omitting the other taxa?
- Identify the predicted effectiveness of the treatment system against the target taxa as compared to the effectiveness of ballast water exchange. This statement should be in the form of an unambiguous experimental hypothesis (or hypotheses) that will be directed tested against the data collected as part of this study.

4.4.3 Experimental Design

The determination of treatment system performance as compared to ballast water exchange will be based upon data collected by the Applicant. These data will be used to test hypotheses relating to treatment. These data will be derived from experiments, with control and treated water, most likely including differing types of source water, organisms, levels of treatment, and several types of controls. It should be remembered that ANS invasions could originate from all trophic level sources.

4.4.3.1 Sample collection for each treatment and control

A. <u>Sampling Design</u>

Discussion

The sampling design (as compared to the experimental design) describes where the samples will be collected within the ballast water system and/or treatment system, the timing of sampling, and number of samples within an experiment, and how samples will be collected and processed.

Key technical points

Outline the general sampling program to be implemented for each trophic level or group in the treatment study. Clearly detail:

- The samples to be collected within the ballast water system and/or treatment system;
- The timing of sampling;
- The number of samples for each experiment;
- How the treatment and control water streams are manipulated;
- How samples are taken for each trophic level;
- Numbers of replicates; and
- How the samples are stored or preserved.

Assist the outline with the inclusion of a diagram.

B. <u>Replication</u>

The study plan should address the questions below:

- How will the sampling program be replicated to provide a measure of the statistical significance of the observations made?
- If not already provided, specifically detail how many samples will be collected at each sampling location per time point.
- How will pseudo-replication be avoided?

Note that it is important to distinguish between sample replication and replication of treatment.

C. <u>Controls</u>

The study plan should address the questions below:

- What portions of the sampling design constitute the experimental controls of the treatment study?
- What are the similarities between control and treatment samples?
- What are the differences other than exposure to the treatment?

4.4.3.2 Description of the number of test runs.

The study plan should address the following:

- Describe the number/location of replicate tests (tests at the same location and environmental conditions, as opposed to the replicate samples within the same test described above). The plan should also address investigating the statistical correlation between primary and performance tests.
- Describe the number/location of comparative tests (tests at different locations or environmental conditions).
- Describe data acquisition and management protocols, including:
    - Describe how the data from the various experiments, tests, and assays will be collected, assembled, and stored as a single body;
    - Data confidence; and
    - Analytical methods, including power analysis.

4.4.3.3 Range of operational and environmental conditions

If the ship's operations schedule is known in advance, the Applicant should provide available water chemistry data for the anticipated test location(s). We recognize that some applicants may not know the test locations in advance or, if they do, may not have such data prior to the tests. In such cases, the Applicant should at least identify any known limiting operating conditions for the proposed treatment components (e.g., a limit of 20 percent absorbance at 253.7 nm for UV treatment systems). Water chemistry data should in any case be collected during the tests, and the Applicant should provide a clear rationale for decisions not to collect particular water chemistry data. Recommended water chemistry descriptors are:

- The type of water (estuarine, coastal, oceanic, lake, river, other freshwater, or other saltwater);
- Seasons for testing;
- pH;
- Temperature;
- Oxidation-reduction potential (ORP);
- Turbidity;
- Total suspended solids;
- Dissolved oxygen;
- Chemical oxygen demand – oxidizer addition systems only; and
- % transmittance at 253.7 nanometers (nm) – UV only.

4.4.3.4 Measurement of treatment system and ballast water exchange performance

The specific experimental design for each test needs to be clearly defined. Include for each experiment a diagram or matrix showing:

- The levels and types of treatments and controls;
- Number of replicate tanks;
- Types of samples;
- Number of samples per treatment/control;
- Time-course of sampling;
- Analytical replicates; and
- External replicates (i.e. repetitions of the entire experiment).

The experimental design should also indicate the statistical model to be employed for testing the hypothesis.

4.4.3.5 Experimental comparison of treatment system to BWE

Describe how the experimental design will compare the treatment system to ballast water exchange, the current legislated performance goal. The description should include the method of ballast water exchange (e.g., flow-through or empty and refill), its frequency, and the methods used to acquire data on flow and other performance descriptors.

4.4.3.6 Reporting procedures

Describe the schedule and outline of the report on the experimental program. It is important to include procedures for data storage, data analysis, instrumentation maintenance and calibration records, and quality assurance information.

4.4.4 Sample Collection and Analytical Protocols (including standard operating procedures)

All protocol descriptions should refer to standard operating procedures where relevant and state clearly how and why they are to be applied.

4.4.4.1 Sample collection and handling

Discussion

Sampling and handling refers to the practical aspects of sample collection, handling, transport and storage. It also includes the preparation or cleaning of sampling gear, personal protective equipment required, chain of custody procedures to be implemented, and any other special considerations that will directly impact the quality of the individual samples.

While the majority of the samples collected will be for biological analyses, the Applicant should also describe how the physical and chemical data will be collected.

Key technical points

- Provide a complete equipment list for each experiment:
    - Identify the type and number of sample vials or bottles;
    - Identify the type and number of support equipment (e.g., pumps, buckets, tubing); and
    - Identify the type and number of personal protective equipment.
- Detail the cleaning and sterilization procedures for equipment contacting biological samples:
    - Describe the procedures for the sample vials or bottles;
    - Describe the procedures for the support equipment; and
    - Describe the procedures for the sample taps.
- Describe the process of sample/data collection:
    - Identify the type and number of sample taps installed in the treatment system;
    - Identify the sample volumes to be collected;
    - Identify the number of replicate samples to be collected;
    - Describe how samples are to be taken and manipulated for each taxonomic group being investigated, and each physical or chemical parameter requiring a sample (such as chemical residual);

  - Describe how physical and chemical parameters not requiring samples will be practically measured (e.g., "A five-gallon bucket will be filled from sample tap A, and the pH probe submerged…"); and
  - Provide a detailed description, with diagrams, of the sampling and handling procedures to be employed throughout a test run.

- Describe the chain of custody procedures.
- Describe the target and maximum hold times and conditions.

Describe the methods for fractionating, dividing, or diluting samples for analyses.

4.4.4.2 Laboratory/field measurement procedures

Biological Laboratory/Field Measurement Procedures

Discussion

Laboratory procedures should include the specific protocols used during the analysis of the samples. These procedures should include the amounts and processes for sub-sampling the field collected samples, and the detailed methods for each biological and chemical assay (including the laboratory standard operating procedures [SOP], instruments used, analytical replicates, the number and type of quality assurance samples, and standards used). The procedures should also include the method detection limits and acceptable variability of each laboratory assay to be employed.

The biological laboratory procedures selected should allow the quantitative assessment of numbers of potential colonizing entities that can be compared with ballast water exchange (BWE).

Viruses and bacteria should be assessed through viable counts based upon dilution series and growth into colonies (or plaques for viruses) on at least two different media. These results should be compared with those from epifluorescence direct enumeration to provide an estimate of the fraction of the total population assayed by each media. Another method (spiking) involves the introduction of a specified bacterial tracer strain into the treatment and control water streams, followed with quantification by viable enumeration on a growth media that uniquely identifies the tracer strain.

Phytoplankton mortality should be determined through species-specific enumeration after treatment, and during time course "grow out" studies.

Quantitative microscopic assessment of cyst or resting stage germination should also be performed.

Mortality of zooplankton and larvae of higher forms should be measured by direct species-specific enumeration of the target taxa, and scoring of viability by observation of organism movement, response to stimulation, and/or activity of "organs" (e.g., heart, cilia, and flagella). Any such subjective scoring methods should be experimentally validated.

Key technical points

Describe in detail the specific biological laboratory protocols to be implemented during the study to assess the mortality or removal of each taxonomic group studied. Be sure to provide the fundamentals and practicalities for any specialized laboratory manipulations and equipment. The detail should be sufficient that an independent investigator knowledgeable in the field, but unfamiliar with this investigation, could duplicate the procedures from your description alone. Where appropriate, clearly describe how the analyst is to determine viability.

Physical Laboratory/Field Measurement Procedures

Discussion

Applicants should measure general water properties to allow for both the interpretation of the test results and the generalization of results to locations other than the specific test site. (Properties that should be collected are included in the questions below.) Knowledge of these properties is frequently important for interpretation and discussion of the biological data. It is critical that the property measurements include all parameters that may significantly affect treatment performance, and addition parameters such as total chlorophyll or nutrient levels may be required on a case-by-case basis.

Key technical points

Provide the (1) methods of measurement (i.e. as applicable, the field instrument manufacturer and model number, or laboratory procedure), (2) methods of instrument calibrations (if applicable), and (3) frequency of instrument calibrations (if applicable) for each of the following physical parameters:

- Flowrate through treatment system and side streams;
- pH;
- Temperature;
- ORP;
- Turbidity;
- Total Suspended Solids;
- Dissolved oxygen;
- Chemical oxygen demand – oxidizer addition systems only;
- Chemical residual – chemical addition systems only;
- % transmittance at 253.7 nanometers (nm) – UV only;
- Other physical or chemical tests planned but not listed above.

Note that instrument calibration logs will need to be maintained on-site. The applicant shall collect the above physical data from the BWT system's influent and effluent on ballasting, and the ship's ballast effluent on deballasting.

4.4.4.3 Sample archives

Sample archives represent a standard practice of storing samples or sample splits (preserved) so that they can be re-examined or confirmed at any time until the test report is finalized.

4.4.5 Quality Assurance and Control for Sampling and Analysis

Discussion

The Applicant should prepare both a Quality Management Plan (QMP) and a Quality Assurance Project Plan (QAPP) consistent with EPA QA/R-2 and EPA QA/R-5, respectively. These documents, along with other guidance documents and other general quality control information are available for download at www.epa.gov/quality. The QMP addresses the quality control management structure and policies of the Applicant's organization (including subcontractors and outside laboratories). The QAPP is a technical document, and is project specific. Note that discussions with the Coast Guard or its agent about the project goals may be required prior to completion of the QAPP.

Note also that for those situations where custom sample ports are installed, there should be analysis of how they contribute to mortality. The analysis should be part of the preliminary work, not the onboard experiments.

4.4.6 Schedule and Milestones

Discussion

To properly manage a project, a schedule needs to be prepared that tracks the status of each major task (including the delivery of equipment by vendors). This level of detail is required to ensure the proper coordination of labor, materials, and finances. It is strongly recommended that the schedule be prepared and tracked with a commercially available software package. The schedule should also indicate:

- The time periods and milestones specified in Navigation and Vessel Inspection Circular (NVIC) 01-04 "Shipboard Technology Evaluation Program (STEP): Experimental Ballast Water Treatment Systems";
- The substantial completion date – the date at which treatment system operations can begin;
- The final completion date – installation is complete;
- The critical path – the necessary sequence of tasks needed to achieve substantial completion (e.g., UV reactor plans must be approved before the reactor can be delivered, or piping installation must be complete before biological testing can begin);
- The float time – the difference between the project's stated substantial completion date and the achievable substantial completion date (e.g., a project with a substantial completion date three months away, but can be completed in two months, has one month of float time);
- The dates to begin and end the primary experimental tasks;
- The dates of scheduled maintenance; and
- The dates of required progress reports and/or meetings.

It may be useful for the Applicant to divide the entire project into three parts:

- Installation and engineering tests of equipment;
- Phase I: Experimental phase, including intensive primary experimental testing; and
- Phase II: Long-term performance monitoring.

Each phase should have its own schedule.

Key point

Provide the installation and test schedule, highlighting significant milestones, major tasks, the critical path, and the float time.

4.4.7 Review Panel observation of primary tests

See Application Requirements document.

4.4.8 Other measures of success

The test team may identify additional measures of success related to the experiment or to performance of the treatment system. An example in the first case would be lack of regrowth in post-treatment holding experiments over an extended period of time. An example measure of system performance would be the ability to achieve and sustain the proper biocide level, which dose-response experiments indicate is 100% effective.

4.5 Engineering and Vessel Operations Matters

4.5.1 Treatment System Configuration

4.5.1.1 Engineering Documentation Package

The following guidelines address the submission of technical documents to the Government. To facilitate, and minimize the time required for, the panel review of submitted materials, applicants are advised to achieve the following to the degree practicable.

- The applicant should collect, assemble, and transmit the system drawings to the Review Panel contact as a single package;
- The package should include a transmittal letter explaining the significance of the transmittal, and a cover sheet that includes the project name, package title, and an index of drawings and other technical material included;
- The applicant should stamp all drawings from sub-vendors with the received date;
- The applicant should ensure that all sub-vendors coordinate the information content of their drawings to avoid contradictions within the package;
- The applicant should assign to each drawing submitted a unique title, drawing number (using a consistent numbering scheme throughout), revision number, page number (if a drawing consists of multiple sheets), and the drawing date;
- The applicant should provide clean, legible copies;
- All drawings should include a list of revision dates; and
- In the event of a drawing revision, the changes should be reflected in the revision number. Further, previous revision hard copies in the applicant's possession should be stamped "Old Revision", and the applicant should provide a copy and transmittal letter to the Review Panel contact. Current revisions should be circled or bubbled to highlight changes.

4.5.1.2 Mechanical Layout Drawings, PFDs, and P&IDs

Provide mechanical layout drawings that clearly identify equipment that is existing and proposed. At a minimum, the drawings should include:

- Existing onboard equipment arrangements;
- Structural and other significant physical features (I-beams, bulkheads, ladders, etc.);
- New treatment equipment and ancillary components;
- Foundations, hangers, and other supports required for new equipment;

- Locations of existing and proposed piping (use double line for large diameters);
- Power panels and conduit;
- Names and numbers of affected machinery compartments;
- Ballast tanks;
- Cargo holds; and
- Any other compartments affected by the treatment system or to be used by the test team for execution of any phase of the experiment.

The application should include Provide Process Flow Diagrams (PFDs) identifying all components and streams, including those of the ship that impact the system (ballast pumps, tanks, etc.).

Piping and Instrumentation Diagrams (P&IDs), if included, should identify the following:

- Equipment types, sizes, ratings, and materials of construction (MOCs);
- Valve types, sizes, and MOCs;
- Line sizes, MOCs, and connection types;
- Design flowrates;
- Sample taps; and
- Instruments, control elements, interlocks, control approaches, etc. and required utilities.

4.5.2 Ship Operations Interface and Crew Labor Impacts

Clearly describe the following:

- Likely ballast loading arrangements; and
- Ship operations interface and crew labor impacts.

4.5.3 Maintenance and Reliability

Identify the expected lifespan and maintenance cycles for the various components of the treatment system. Include the manufacturer's recommended spare parts list for each major piece of equipment.

4.5.4 Classification Society Approval

The design and installation of the treatment system must be reviewed and approved by a classification society belonging to the International Association of Classification Societies (IACS), e.g., the American Bureau of Shipping, Lloyd's Register, or Det Norske Veritas. The review should include a letter summarizing the society's activities and the results, stamped system installation and ship's arrangement drawings, and an engineering review of the treatment components specification and construction.

4.6 Human Health and Safety

4.6.1 Exposure to treatment system media

Describe any potential exposure of test team or ship's crew to the active components of the treatment system, e.g., UV radiation, chemical biocide. Identify planned actions for eliminating or minimizing, monitoring, and treating such exposure.

4.6.2 Safety impacts of treatment system

Describe any potential impacts of installed system to the ergonomics of machinery space operation, crew escape arrangements, and pumping and damage control arrangements. Assess the effect of the added weight and moment of the installed system.

4.7 Long Term Treatment System Performance Monitoring

The Applicant must describe the proposed protocols for monitoring of system performance throughout the STEP equivalency period. General requirements appear below. The particulars of these requirements appear in the "Application Requirements" document and are repeated herein.

4.7.1 Treatment Performance

Provide for periodic monitoring of biological conditions and treatment system effectiveness, and an approach for validation against the original test results. Provided that the source waters or species present do not change, the ability of the treatment approach to disinfect ballast water should not alter over time. That is, the use of the treatment system is not anticipated to promote the development of resistant species in the source waters, or to significantly alter the existing populations; and a change in system effectiveness is due to a failure in the system or operations.

4.7.2 Engineering Performance

Provide a plan for equipment life cycle management (maintenance, testing, and repair through anticipated service life), to ensure reliable and consistent operation.

4.7.3 Reporting Requirements

During the experimental phase (Years 1 - 5), the Applicant is required to provide annual and quarterly reports on the monitoring of system performance, maintenance and operations issues, summary of ship's movements including changes from anticipated service, problems and system breakdowns, and health, safety, and environmental aspects. During the monitoring phase (post Year 5), the Applicant is required to provide annual reports only.

The quarterly reports should provide:

1) If applicable, installation progress to date, and an updated installation schedule (identify and date the major tasks, the critical path, float time, milestones, substantial completion, and final completion).
2) Problems with, or concerns relating to, the performance or operation of the treatment system encountered over the past quarter (include dates of system downtimes, analyses of downtime causes, descriptions of resolutions, and steps taken to prevent reoccurrences);
3) Changes (implemented or planned) to the treatment system, operational procedures, or experimental program (planned changes should be accompanied by justifications, and should not be implemented unless reviewed by the Review Panel and approved by the Coast Guard);
4) Instrument calibration logs for the past quarter;
5) The current contact in the organization of the Applicant overseeing the project and installation (include name, title, business address, and phone numbers); and
6) Emergent issues in human health and safety, and compliance with environmental laws and permits.

The Annual Reports should include:

1) If applicable, a summary of installation activities;
2) A signed statement confirming that substantial completion of the installation has been achieved (first year only);
3) Ship itineraries utilized for the past year and scheduled for the upcoming year (include ports visited and voyages performed with approximate dates). If detailed itineraries for the upcoming year are not available due to unpredictable operations, the nature of the future operations should be reported to the level of detail known (in this case, the Review Panel and the Coast Guard should consider shifting the reporting of upcoming schedules to the quarterly reports);
4) Locations and volumes of ballasting and deballasting operations over the past year (to be tracked in logbooks), and anticipated for the upcoming year (to be supported by above itineraries). As above, the Review Panel and the Coast Guard should consider shifting the forecasting of ballasting operations to the quarterly reports for ships with loosely defined schedules;
5) Descriptions and dates of BWT system routine maintenance performed over the past year, and planned for the upcoming year;
6) Invoices (with quantities) for chemicals, UV lamps and sleeves, or other items purchased over the past year for the proper operation of the treatment system (should demonstrate adequate use of the treatment system);
7) Anticipated quantities of chemicals, UV lamps and sleeves, or other items required during the upcoming year for the proper operation of the treatment system (include backup calculations justifying quantities);
8) A summary of the problems with or concerns relating to the performance or operation of the treatment system encountered and the resolutions implemented over the past year (details should have been provided in the quarterly reports);
9) Summary of changes (implemented or planned) to the treatment system, operational procedures, or experimental program (details should have been provided in the quarterly reports); and
10) Report of primary experimental and performance monitoring data, with interpretations.
11) Summary and synthesis of the BWT performance from the installation data, with interpretation.
12) Actions on and resolution of emergent issues in human health and safety, and compliance with environmental laws and permits.

The Review Panel will consider the requirement of additional information on a case-by-case basis.